National Aeronautics and Space Administration

Computing, Information and Communication Technologies Program
Information Technology Strategic Research Project
Intelligent Controls and Diagnostics Sub-Project

Intelligent Automation
UPN 302-05
FY04 Plan

Agreements:

________________________________ __________
Joseph J. Totah Date
Approve: Level III ICD Sub-Project Manager

________________________________ __________
John T. Kaneshige Date
Submit: Level IV IA Task Lead

1. Background

Intelligence can be defined as the ability to "do the right thing" when faced with a complex decision-making situation. Vehicle intelligence, capable of making reliable decisions with limited human intervention, has the potential for improving safety, enhancing mission effectiveness, and enabling extreme missions. To accomplish these goals, on-board systems must exhibit increasingly higher levels of automation capable of responding to changing goals and objectives, while taking corrective actions in the presence of internal and external events.

Current levels of automation allow pilots to assign direct tasks to automatic systems, such as monitoring/caution and warning systems or automatic pilots. These autopilots have been used in commercial aircraft for a number of years. While their design can incorporate many aspects of a pilot's experience, they do not possess the reasoning or learning abilities of a pilot. As a result, pilots are still responsible for supervising the performance of these systems as well as providing direction in the event of required changes. By applying intelligent methods of automation, pilots, ground-based operators, or autonomous executives can defer the responsibilities from performing and supervising tasks, to focus on managing goals and objectives.

The Intelligent Automation (IA) research task was established to explore the application of intelligent methods for achieving increasingly higher levels of automation. This task is part of the Intelligent Controls & Diagnostics (ICD) sub-project of the Information Technology Strategic Research (ITSR) project, within the Computing Information Communication Technology (CICT) program.

2. Objective

The objective of this research effort is to develop comprehensive methods for achieving increasingly higher levels of automation for flight vehicles. Several core capabilities will be investigated in order to automate many of the actions currently performed by pilots. These actions include the internal management of a vehicle's health and the determination of action using planning and decision-making models to give the vehicle goal directed self-reliant behavior with a high degree of autonomy. Automation interfaces will also be explored in order to address human interaction with increasingly higher levels of automation.

3. Technical Approach

A conceptual architecture has been developed under which various methods for achieving the desired goals of health monitoring, situation awareness, and strategic and tactical maneuvering can be explored (Figure 1). Automating strategic and tactical maneuvering functions is a key element in intelligent flight control. Intelligent flight control and health management requires tight integration within the control loop. For example, an effective FDIR solution must collect sensor data, process it, and assess system readiness in real-time. In case of degradation or failure, the failure source must be isolated promptly and its impact on mission evaluated. If the failure is in a redundant subsystem, the reconfigured system can continue its mission, possibly in a degraded mode. Otherwise, the impact of the failure must be assessed and mission priorities and available capabilities matched to modify the mission or to select an alternative mission. Intelligent maneuvering technologies capable of flying aircraft in the presence of dynamic goals and objectives, while taking corrective actions in the event of external and internal disturbances, are required. Interfaces that will allow pilot interaction with the automated system require novel graphical displays of vehicle and environment parameters and status, multimodal interaction capabilities, and intelligent agents to support the pilot in rapid assessment of the current operating situation. These technologies will be developed to provide increasingly higher levels of automation so that pilots, ground-based operators or autonomous executives can defer the responsibilities of performing and supervising tasks, to focus on managing goals and objectives.

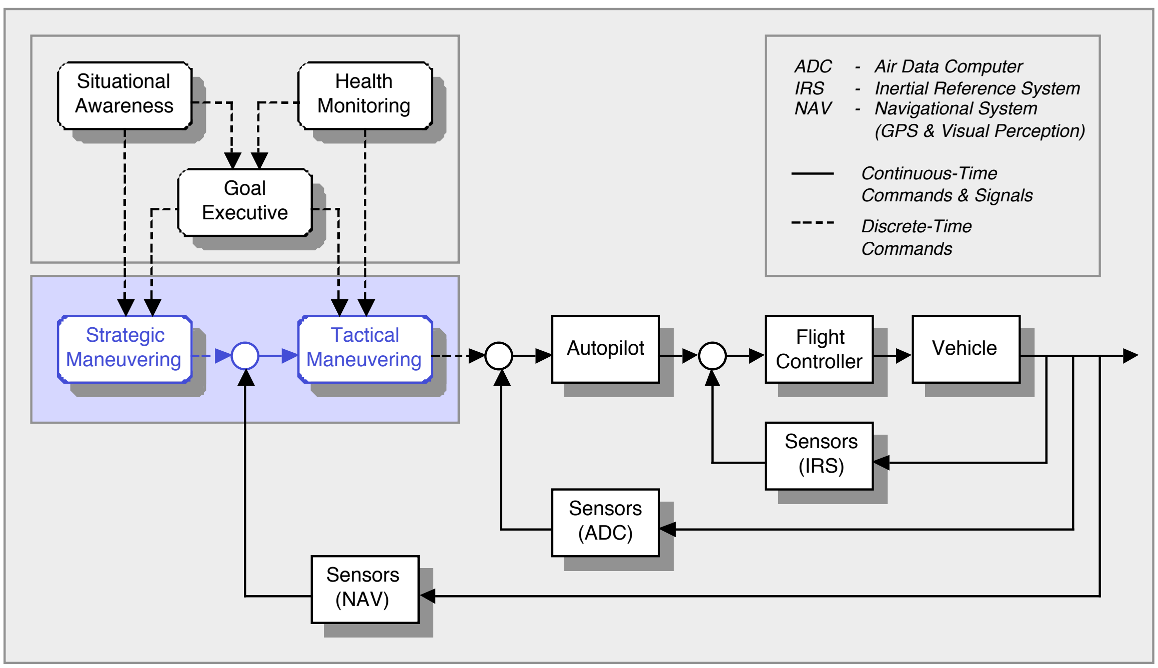


Figure 1. Conceptual Architecture

Health Management

The Health Management subtask is pursuing the development of several core capabilities that are necessary to achieve the goal of intelligent automation. The vehicle systems must be able to detect and identify anomalous behavior in system components and functions, degraded performance, and structural interactions and margins. The management of system health requires a hierarchical architecture that can capture the interdependencies of subsystems and enable the identification of root failures. The health management system must be able to manage multi-level failures and identify and limit the propagation of cascading failures. Failures must be prioritized by criticality so that saturation and shutdowns can be avoided, allowing a degraded system to complete its mission. These capabilities will be implemented in a Health Management (HM) System that can communicate to a human operator or Goal Executive, which in turn can provide the coordination of Intelligent Maneuvering system. System status will be relayed to the pilot through multimodal pilot interfaces.

A real-time monitoring and diagnosis system is essential to reducing the likelihood of loss of mission due to sudden malfunction. Dynamic systems typically operate in many modes to perform the necessary functions. Developing system models that treat mode-dependent behavior appropriately and efficiently is a challenge for model-based diagnosis, however the robustness that is provided by these types of diagnostic systems is desirable. This work will focus on investigating various available diagnostic models and how they represent mode behavior. The interface of this system to the human operator and other intelligent agents in the architecture will be explored.

Intelligent Maneuvering

The Intelligent Maneuvering subtask explores the development of technologies capable of making reliable decisions when flying aircraft under varying conditions. The application of heuristics, artificial intelligence concepts and other soft computing techniques will be explored, in order to replace the experience, reasoning and learning abilities of pilots.

In terms of achieving a flight-path goal, a pilot's behavior can be captured through a layered model consisting of discrete-time strategic planning and tactical maneuvering, and continuous-time manual control (Figure 2). Just as pilots use different mental approaches to perform each task, different automation techniques will be applied that correspond to the time restrictions and computational nature associated with each task. Strategic maneuvering will perform long-term planning that meets mission objectives, within mission constraints and performance limitations, while incorporating vehicle performance assessments and accommodating other unforeseen circumstances. Tactical maneuvering will perform time-critical flight path operations, which includes aggressive maneuvers in the presence of unexpected obstacles, by selecting discrete flight modes and targets in order to achieve strategic maneuvering objectives. Conventional control techniques can be used to automate the continuous-time control task of the pilot. However other adaptive control techniques will also be explored in order to improve maneuvering handing qualities, and increase the accuracy of performance models used for decision-making. These performance models represent the equivalent of a pilot's "understanding" of the internal performance of the aircraft as well as aircraft systems. These intelligent maneuvering technologies will be integrated with conventional systems and other information-based technologies to form an integrated architecture (Figure 1).

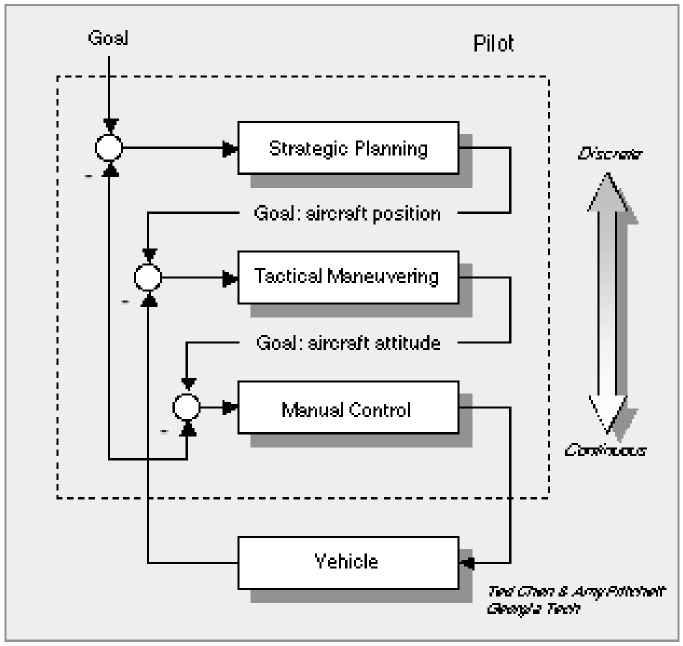


Figure 2. Pilot Behavior Hierarchy

Various methods for performing strategic-planning *(e.g. evolutionary algorithms)* will be explored, in order to achieve high-level commands (or mission goals and objectives). Time-critical methods for performing tactical maneuver selection *(e.g. artificial immune system algorithms)* will also be evaluated, in order to comply with planning objectives and respond to unexpected conditions Actions are not limited to merely changes in the aircraft speed and orientation. Some actions also change the aircraft dynamics itself, such as extension of flaps and gears or the dumping of excess fuel.

Situational Awareness Interface

Automation changes the way a human deals with problems. Whether automation helps or hinders a person's ability to handle the task at hand is dependent on the human-computer interface. In mobile applications, such as piloting airplanes, the popular WIMP (windows, icons, menus, pointing devices) interfaces have a number of drawbacks that could lead to increased workload for the user. In these eyes-busy situations the user is not able to devote his full concentration on visually extracting necessary information. Rather than presenting all data graphically, the information needs to be distributed to the more underutilized senses. The data also need to be pre-processed so that the automation helps the user perform his task rather than overwhelming him. The interface should integrate information about the user, his current location, the task, and the application domain and anticipate the user's needs, allowing him to spend more time on decision making rather than system monitoring and situation determination. In this research, interfaces will be explored that go beyond the WIMP interface and incorporate a more human-centered approach in which people and their work are uppermost and natural human interaction modes are primary. Anticipatory, multimodal interfaces for systems with increasingly higher levels of automation are of particular interest in this work.

The anticipatory aspect will be realized through the use of interface agents. The metaphor associated with interface agents is that of the personal assistant. The ultimate interface agent adapts to an individual user, and using its knowledge of the task, the domain, and the current context, it reduces the user’s workload by anticipating the user’s needs and taking the initiative in performing some tasks. Because different users have a varying need for supporting or contextual information, the interface agent uses machine learning techniques to accommodate an individual user’s preferences. Different learning techniques (e.g. supervised classification using decision trees) will be investigated to adapt the interface to an individual’s preferences.

The multimodal aspect will allow the user to interact with an intelligent automation system to retrieve/receive vehicle health information, maneuver selection, or high-level goals by utilizing more of his senses, specifically auditory and haptic, in addition to the visual. Because both audio and haptic feedback are omni-directional and have low real-estate needs in a cockpit, they are a good supplement to visual information presentation.

Summary

The objective is to develop and mature intelligent automation technologies for the purpose of intelligent tactical and strategic vehicle maneuvering. These technologies will be developed both as a pilot aid, for delegating tasks during vehicle operations, and for controlling remote or autonomous vehicles. A high degree of adaptability and autonomy must be exhibited for the purposes of automatically compensating for a broad spectrum of damage or failures, cooperating with other vehicles, and compensating for external disturbances or threats.

The goal is to develop an intelligent maneuvering system capable of carrying out defined flight-path goals for a wide range of vehicle classes, including fixed-wing, rotorcraft, and reusable launch vehicles. Specific attention will be paid to coordinating this work with the C-17 project at Dryden Flight Research Center. The system will incorporate planning and decision-making models to give the vehicle goal directed self-reliant behavior with a high degree of autonomy. The application of related research and technologies, with potential for supporting this goal, will also be investigated.

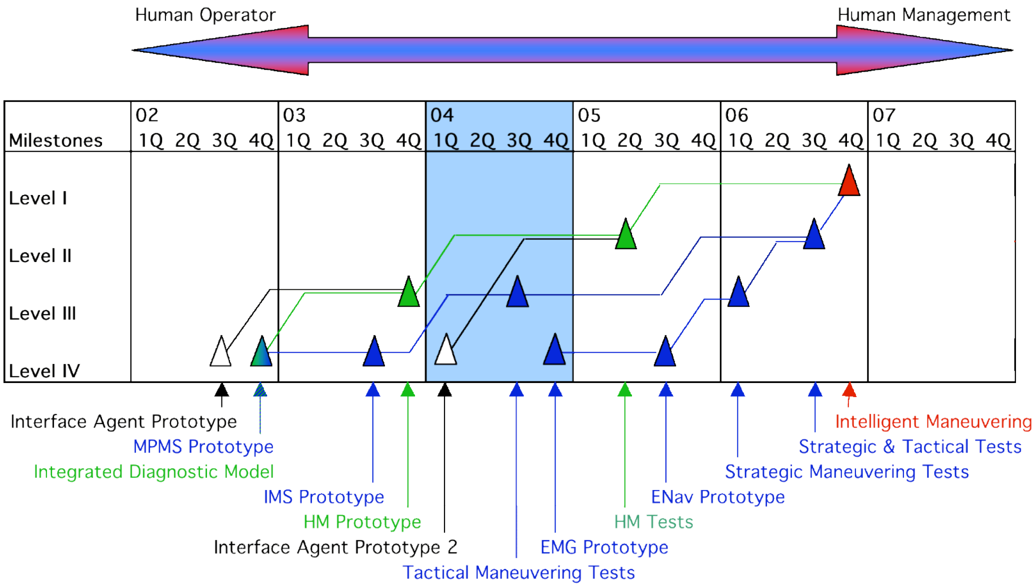
4. Milestones

PCA 8 *Project*/Sub-Project Milestones	**Due Date**	**Metrics**
8.11 Demonstrate an intelligent maneuvering system capable of incorporating planning and decision-making models to give the vehicle goal directed self-reliant behavior with a high degree of autonomy.	*Sep-06*	*1) An intelligent maneuvering system that incorporates long-term planning to meet mission objectives, within mission constraints and performance limitations, while incorporating vehicle performance assessments and accommodating other unforeseen circumstances. 2) A system capable of performing time-critical flight path operations, which includes aggressive maneuvers in the presence of unexpected obstacles, by selecting discrete flight modes and targets in order to achieve strategic maneuvering objectives. The development of an intelligent maneuvering system capable of carrying out defined flight-path goals for a wide range of piloted and uninhabited vehicle classes, including fixed-wing, rotorcraft, and reusable launch vehicles. Success criteria will be the ability of the system to achieve equivalent pilot performance.*
8.11.1 Integrate capabilities of diagnostics and control with multimodal interface.	Mar-05	A health management system capable of managing multi-level failures, and identify and limit the propagation of cascading failures. Success criteria are that failures must be prioritized by criticality so that saturation and shutdowns can be avoided, allowing a degraded system to complete its mission. A health management system capable of communicating to a Goal Executive, which in turn will provide the coordination of Intelligent Maneuvering system. System status will be relayed to the pilot through multimodal pilot interfaces.
8.11.2 Perform maneuver selection tests in a simulated environment for UAV applications.	Jun-06	Evaluate decision-making in the presence of internal and external disturbances. Maneuver selection effectiveness equivalent to that of a human operator/pilot.

Task-Level Milestones:

Milestone	**Description**	**Metrics**
Interface Agent Prototype - Level IV - 3QFY02 (complete)	Speech interface integrated with machine learning of situational data.	Evaluate effectiveness of speech interface and interface agent.
MPMS Prototype - Level IV - 4QFY02 (complete)	Develop Model Predictive Maneuver Selection (MPMS) prototype.	Evaluate MPMS for tactical maneuvering.
Integrated diagnostic model - Level IV - 4QFY02 (complete)	Develop model of control system (software and actuators).	Evaluate multi-signal model for integrated hardware and software systems.
IMS Prototype - Level IV - 3QFY03 (complete)	Develop Immunized Maneuver Selection (IMS) prototype.	Evaluate IMS for tactical maneuvering.
HM Prototype - Level III - 4QFY03 (complete)	Diagnostics integrated with control in simulated environment.	Evaluate diagnostic algorithm capability to support intelligent maneuvering.
Interface Agent Prototype 2 - Level IV - 1QFY04 (complete)	Investigate tactile feedback for control.	Evaluate tactile interface techniques.
Tactical Maneuvering Tests - Level III - 3QFY04	Perform tactical maneuver selection tests in a simulated environment.	Evaluate tactical maneuver selection under various circumstances.
EMG Prototype - Level IV - 4QFY04	Develop Energy Management Guidance (EMG) prototype.	Evaluate EMG for strategic maneuvering.
Heath Management Tests **- Level II** (PCA 8.11.1) **- 2QFY05**	*(see PCA 8.11.1)*	*(see PCA 8.11.1)*
ENav Prototype - Level IV - 3QFY05	Develop Evolutionary Navigation (ENav) prototype.	Evaluate ENav for strategic maneuvering.
Strategic Maneuvering Tests - Level III - 1QFY06	Perform strategic maneuver selection tests in a simulated environment.	Evaluate strategic maneuver selection under various circumstances.
Strategic and Tactical Maneuvering Tests **- Level II** (PCA 8.11.2) **- 3QFY06**	*(see PCA 8.11.2)*	*(see PCA 8.11.2)*
Intelligent Maneuvering **- Level I** (PCA 8.11) **- 4QFY06**	*(see PCA 8.11)*	*(see PCA 8.11)*

5. Schedule



6. Resources / Budget

Labor:

4.00	FTE
3.35	WYE

Procurement (excluding labor):

$0.398M	Procurement
$0.020M	SERV-I

7. Management Approach

Deliverables (FY 2004):

- Research Technical Paper compliant with Ames Publication procedures (ARC 310 and ARC 1676), or equivalent procedural compliance for tasks located at NASA Glenn Research Center.
- Simulation / demonstration of technologies.
- Physical / experimental data acquisition and/or technology validation.

Environment / Equipment:

- All research will take place in the NeuroEngineering Laboratory Rm. 281 / Bldg. 269, flight simulation facilities (CVSRF in Bldg. 257 or the VMS in Bldg. 243), and UAV flight test assets.

Compliance with Standards and Codes:

- 53.ARC.0009.2.1 Publication of research
- 53.ARC.0009.2 Management and performance of research

Applicable Quality System Procedures and Work Instructions:

- 53.ARC.0004.1
- 53.ARC.004.2

<u>Process Monitoring Methods/Procedures</u>:

- Performed to satisfy all Level I business requirements, described below:

Type	Frequency	Purpose	Reporting By	Content/Format	Comments
Technical Highlights	Weekly	Status updates and/or highlights	L4 Task Leads and Technical POCs	Informal text of monthly progress - indicate "None" for negative replies *e-mail text; web-site entry*	Unless significant progress is reported, can be brief
Quarterly Progress	Quarterly	Program Management Council (PMC)	L2 Managers	Text (and accompanying graphic, if any) of quarterly progress towards L1/L2 milestones *e-mail text; electronic copy of graphic; web site entry (under development)*	Progress towards all active L2/L3 milestones should be reported
Technical Highlights	Quarterly	Program advocacy and reviews	L2 Managers	One page text (Bullets: Objective, Background, Accomplishment, Future Plans) and one page graphic *e-mail text; electronic copy of graphic; web site entry (under development)*	Technical Highlights are used to promote the CICT Program and represent significant accomplishments
Milestone Summaries	Milestone due dates or completion	Program advocacy and reviews	L2 Managers	Detail description of milestone accomplishments relative to goals and success metrics. Background material including graphics, technical reports, publications, etc. *e-mail text, electronic copies of graphics, hardcopies of reports*	
Budget and Workforce Tracking	Monthly (5th working day of each month)	Status reports to ITSRPO and CFO	Center POCs for resource management	Spreadsheets, graphs at the 5-digit level. Include variance explanation for +/- 10% variances *e-mail text; electronic copy of graphs; web site entry (under development)*	Planned vs. actual commitments obligations and accruals at 5-digit level. Planned vs. actual CS and SSC workforce.
ATAC Sub-committee Reviews	Annual	To review and provide advice on research efforts	L1, L2, and L3 Managers and Technical POC's	Program, project, and sub-project plan on-site review on status, approach, and technical accomplishments	
LCPMC	Annual	To review status, budget, and milestones	L1 and L2 Managers	Program and Project tracking of budget and milestones	